erals and enhanced by the development of dissolution porosity in silicate grains and carbonate cement.

Upward-coarsening sandstone sequences, 3 to 30 m thick, contained in the Eagle-Telegraph Creek-equivalent Gammon Shale, accumulated tens to hundreds of kilometers seaward (eastward) of the strand. These sandstones are transitional between conventional reservoirs and low-permeability reservoirs. Near the bottom of each sequence, porosity averages 15% and permeability averages 1 md. Upward through each sand accumulation, loss of allogenic clay and increasing sand content and grain size enhance reservoir properties. Porosity and permeability attain 25% and 150 md near the top of each sequence. Reservoir quality is controlled by allogenic clay content, intensity of bioturbation, precipitation of authigenic minerals, and the dissolution of cements and detrital grains.

The greatest volume of natural gas occurs in low-permeability mudstones of the Gammon Shale, which are identical to offshore equivalents of the Milk River Formation in southeastern Alberta. The reservoirs are silty shales containing discontinuous lenses and laminae of silt or very fine sand, a few millimeters or less in thickness. Effective porosity is confined to passageways within the laminae or to spaces among loosely packed clay platelets between clastic grains. Porosities range between 10 and 20%, permeabilities are commonly less than 0.1 md, and pore-entrance diameters are normally 0.1 μ or less. Because of the amount and composition of allogenic clay, the reservoirs are highly water sensitive and display very high water-saturation values. Although economic flow rates are only achieved through fracturing, subsequent production has been predictable and profitable.

GAUTIER, DONALD L., U.S. Geol. Survey, Denver, CO

Diagenesis in Shallow Conventional and Low-Permeability Biogenic Methane Reservoirs of Eagle Sandstone, Montana

The Upper Cretaceous Eagle Sandstone and equivalent rocks in north-central and eastern Montana provide an excellent opportunity to investigate postdepositional effects in gas reservoirs that have never attained thermal conditions sufficient for the generation of petroleum.

Investigations reveal that these reservoirs display inorganic diagenetic features similar to those of rocks having a burial history suitable for the formation of oil or thermogenic gas. These features are observed in both high-permeability and low-permeability reservoirs. Complex paragenetic sequences such as the following are common: (1) authigenic clay formation, (2) quartz overgrowth, (3) calcite cement and replacement, (4) carbonate dissolution, and (5) additional authigenic clay formation. Exotic phases, such as authigenic tourmaline, are observed locally. More importantly, there is widespread evidence of former calcite cementation and replacement, especially of plagioclase, followed by carbonate dissolution. The distribution of these features suggests that calcite has at various times occupied virtually every pore in many of the Eagle reservoirs. However, several lines of evidence, including the timing of gas generation and entrapment and the distribution of calcite in the Eagle Sandstone, suggest that the reservoirs have never been completely sealed by carbonate rock.

Thermal maturation of organic matter is not a prerequisite for the development of secondary porosity, nor for the development of minerals potentially hazardous to well-completion and treatment procedures. In addition, unequivocal evidence demonstrates that dissolution porosity can be produced without a previous period of total destruction of reservoir quality.

GEESAMAN, RICHARD C., Exxon Minerals, U.S.A., Albuquerque, NM and BRENT J. VOORHEES, Texaco Inc., Denver, CO

Facies and Depositional Tectonics of Middle Jurassic Carmel Formation, Southern Utah

The Middle Jurassic Carmel Formation of southern Utah is divided into two informal members deposited during a major transgressive-regressive cycle. The relatively thin lower member was deposited in a shallow, subtidal, marine to coastal, sabkha environment that advanced southeastward, onlapping and reworking coastal dunes of the Navajo and Page sandstones. Lithofacies of the lower Carmel include calcareous mudstone, bivalve micrite, oolitic grainstone and packstone, ostracod pelletal micrite, dolomicrite, algal stromatolites, aphanitic dolomite, and minor nodular gypsum and sandstone.

The sporadic northwest retreat of the Carmel Sea and progradation of coastal sabkha and continental sabkha and dune sediments is recorded in the thick upper member of the Carmel. Lithofacies include algal stromatolites, aphanitic dolomite, calcareous mudstone, nodular gypsum, horizontal to gnarly-bedded sandstone, and cross-bedded sandstone.

The lower Carmel undergoes rapid west to east thinning and facies changes, indicating that during the early Middle Jurassic (late Bajocian) the Hurricane fault was a tectonic hinge line that separated a westward tilting unstable shelf slope to the west from an unstable shelf to the east. Furthermore, lower Carmel facies, isopach anomalies, and regional stratigraphic and structural correlations indicate that anomalous subsidence and sedimentation in the present Sevier-Paunsagunt fault zone were contemporaneous and genetically related to initial deformation of the Middle Jurassic San Pete-Sevier rift of the hinge-line region of central Utah.

GHOSH, SANTOSH KUMAR, Ministerio de Energía y Minas, Mérida, Venezuela

Carbonate Facies of Peñas Altas Formation, Venezuela—Case Study of Cretaceous Shallow-Marine Shelf

The Peñas Altas Formation, deposited in a shallow-marine shelf environment, forms the lower part of a Cretaceous transgressive sequence. Starting with a basal conglomeratic clastic wedge, the formation passes upward into a shelf facies and culminates in the basinal Luna Formation. The important carbonate lithofacies include (1) algal wackestones with trace fossils of *Pla-*

nolites, Chondrites and *Thalassinoides,* (2) glauconitic wackestones, (3) rudist-*Orbitolina* wackestones, and (4) oolitic-bioclastic grainstones. These carbonate facies are associated with cross-bedded coastal marine and platform quartzarenites and silty carbonaceous lagoonal facies. Facies 1, which overlies the basal transgressive clastic wedge, is interbedded with thin rudist-bearing wackestones and algal grainstones. This algal wackestone facies represents deposition in restricted marine back-bar/back-reef conditions. The glauconitic facies 2 was also deposited in a relatively tranquil environment of the back-bar. Facies 3, of alternating thin *Orbitolina* and rudist-wackestone, contains numerous biogenic tubular structures filled with *Orbitolina* grainstone. The rudists (caprinids and Toucasia) are mostly unoriented and matrix-supported. This facies probably represents local reefal-biostromal development on an oxygenated marine shelf. The oolitic grainstone (facies 4) is a facies diagnostic of shoaling-upward sequences within or at the margin of the platform. Ammonites and ahermatypic solitary corals at the top indicate a gradual deepening of the environment. The overlying basinal Luna Formation represents the acme of transgression of the Cretaceous period which resulted in an overall upward-fining megacyclothemic sequence.

GOLUBIC, S., A. H. KNOLL, and W. RAN, Boston Univ., Boston, MA

Morphometry of Late Ordovician Microbial Borings

Microborings within Late Ordovician shells of the brachiopod *Raphinesquina alternata* from the Tanner Creek Formation, Richmond Group, of southeastern Indiana, were studied by scanning electron microscopy of their resin casts. The shells have been exposed to microbial boring in quiet and illuminated waters below the wave base and then buried with skeletal fragments of ramose bryozoans, echinoderms, trilobites, and rugose corals.

Four morphotypes of microborings have been characterized on the basis of shape, branching patterns, and diameter size and variation. Statistically evaluated measurements for populations of microborings indicate four ichnotaxa.

GOTER, EDWIN R., Shell Oil Co., Houston, TX, and GERALD M. FRIEDMAN, Rensselaer Polytechnic Inst., Troy, NY

Deposition of Enewetak Atoll Reef, Middle Pleistocene to Holocene

Cyclic deposition and diagenesis of a large atoll reef, associated with major eustatic sea-level fluctuation, is documented in six cores from the northeast (windward) reef of Enewetak Atoll. To 250 ft (76 m) depth, the reef section comprises six primary depositional packages that represent periods of reef growth during Pleistocene and Holocene high sea-level stands. These depositional packages are separated by unconformities, former subaerial exposure surfaces, which are demarcated by paleosols. During emergent periods at low sea-level stands, the reef was subjected to meteoric-water diagenesis. However, the depositional textures generally are well preserved. Diagenetic textures, most indicative of meteoric-vadose diagenesis, usually have only partly replaced original textures. An oceanward shift of reef environments through time is apparent in a large-scale view of the cores. Reef crests in succeedingly younger depositional packages apparently are offset oceanward. Younger marginal lagoonal deposits unconformably overlie older backreef deposits that unconformably overlie older reef-crest deposits. Within depositional packages, influence of rising sea level on facies development is evident. Subaerial surfaces flooded by rising sea level were rapidly colonized by both solitary corals and patch reefs of diverse composition. Rapid upgrowth of oceanward reef crests led to moderation of wave energy in backreef areas and great increase in deposition of sediment which locally buried and killed patch reefs. Shoaling of backreef areas by sediment aggradation to a stabilized sea level resulted in renewed development of patch reefs and deposition of coarser sediment.

GOVEAN, FRANCES M., Amoco Research Center, Tulsa, OK

Calcification Model and Secondary Calcification Effects on Fossil *Bolivina seminuda*

Fossil individuals of *Bolivina seminuda,* studied with an SEM, reveal a tripartite test-wall ultrastructure composed of (1) an underlying organic lining with pore structures, (2) a radial calcitic layer bounded by organic membranes, and (3) a calcitic surface veneer. A calcification model for *Bolivina seminuda* is proposed where the inner organic lining is precipitated first. Overlying this is a layer composed of radial calcite with the crystallographic C-axes aligned perpendicular to the test wall. This calcite is laid down in successive packets bounded above and below by organic membranes. Above this is a surface veneer composed of randomly oriented calcite rhombs. This model differs from some proposed models by the absence of a randomly oriented calcite rhomb layer incorporated with each packet of radial calcite and by attributing the surface veneer to inorganic precipitation.

The surface veneer is interpreted as diagenetic in origin and not precipitated by the organism. The diagenetic calcification patterns at first enhance preexisting surface sculpture and then gradually mask it. This coating makes the different phenotypes of *Bolivina seminuda* similar to one another and to other species in appearance. The effects of this calcification must be considered in taxonomy, biostratigraphy, and paleoenvironmental interpretations.

SEM studies of the ultrastructure of *Bolivina seminuda* indicate which test-wall parameters are controlled by genetics, environment, and postdepositional (or postmortem) history. The raw data may be of use in subsequent investigations of paleoenvironments, taphonomy, and postdepositional (or postmortem) history.

GRADSTEIN, FELIX, Geol. Survey Canada, Dartmouth, Nova Scotia, and FRITZ AGTERBERG, Geol. Survey Canada, Ottawa, Ontario

Application of Statistical Models in Continental Margin Biostratigraphy

Stratigraphic events defined by the highest or lowest